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The impact of an intermediate temperature buffer on the growth of GaN on an AlN template by hydride vapor phase epitaxy

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ABSTRACT

The present study focused on the effect of an intermediate-temperature (IT; ~900 °C) buffer layer on GaN films, grown on an AlN/sapphire template by hydride vapor phase epitaxy (HVPE). In this paper, the surface morphology, structural quality, residual strain, and luminescence properties are discussed in terms of the effect of the buffer layer. The GaN film with an IT-buffer revealed a relatively lower screw-dislocation density (3.29×10^7 cm^{-2}) and a higher edge-dislocation density (8.157×10^9 cm^{-2}) than the GaN film without an IT-buffer. Moreover, the IT-buffer reduced the residual strain and improved the luminescence. We found that the IT-buffer played an important role in the reduction of residual strain and screw-dislocation density in the overgrown layer through the generation of edge-type dislocations and the spontaneous treatment of the threading dislocation by interrupting the growth and increasing the temperature.

1. Introduction

Gallium nitride (GaN) is an attractive material for use in various applications such as optoelectronic devices, during high temperature, and in high-power electronic devices [1–3]. However, due to the lack of a homogeneous substrate, GaN films are usually grown on heterogeneous substrates such as sapphire. Consequently, without buffer growth, the large lattice mismatch (~16.1%) between the GaN and the sapphire and the large difference in thermal expansion coefficients [4] hinder the growth of single crystalline GaN directly on a sapphire substrate. Hence, to accommodate these mismatches, buffer growth is a very important technique for GaN film growth, and many researchers have proposed a wide variety of buffer growth techniques to obtain high quality GaN films [5–8]. However, the aim of recent buffer growth technique has changed and the effect of a buffer layer has become more complex. For example, a buffer is sometimes used to make free-standing films [9], while at other times it is used to control the polarity of films [10]. Whatever the purposes be, each buffer should provide a proper matrix for successful epitaxial growth. A low temperature (500–600 °C) buffer growth is a well-known growth technique. It enhances the initial nucleation of GaN on Al_2O_3, and widely adopts to grow GaN films using various gas-phase growth methods. However, in the hydride vapor phase epitaxy (HVPE) of GaN thick layers, nevertheless the similarity of the main growth temperature (1050–1080 °C) with other methods, we found that an intermediate temperature (IT; ~900 °C;) buffer helps to improve the crystallinity of overgrown thick-GaN film even on AlN templates. Hence, an investigation of the effect of IT-buffer layer is essential to obtain high-quality film. In the present study, we investigated the roles of IT-buffer (T_g=900 °C) for the growth of GaN film ($T_g>1000$ °C) on an AlN template by hydride vapor phase epitaxy (HVPE).

2. Experimental

AlN templates grown on (0 0 0 1) Al_2O_3 substrates were prepared by metal organic chemical vapor deposition (MOCVD). Trimethylaluminum (TMA) and ammonia (NH_3) were used as Al and N sources, respectively. The substrate temperature was ~1080 °C for AlN films, and the thickness was controlled to be 2 μm. Subsequently, we prepared two GaN samples: one was a GaN film without an IT-buffer layer (sample A), and the other was a GaN film grown on an IT-buffer layer (sample B), as shown in Fig. 1. The GaN films were grown on AlN/sapphire templates by

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hydride vapor phase epitaxy (HVPE). The growth began with a nitridation process using an AlN/sapphire template for 30 min at 1080 °C; subsequently, 10 μm thick GaN films were grown at 1040 °C. Sample B contained a 5 μm thick IT-buffer grown on the template at 900 °C.

The surface morphology was analyzed using atomic force microscopy (AFM). An X-ray diffraction (XRD) measurement was performed to confirm the crystal quality and residual strain of the films. To characterize the optical properties, low-temperature (11 K) photoluminescence (PL) was measured using the 325 nm line of a He–Cd laser as an excitation light source.

3. Results and discussion

It is well-known that use of a low-temperature buffer layer (LT-buffer; $\Delta T > 500$ °C) has resulted in substantial progress in the research of nitride semiconductors [11,12] by reducing the surface energy of a sapphire substrate. Also, the crystallinity of GaN is reportedly closely related to the buffer growth temperature [13], and much research has focused on the role of a low-temperature buffer [14]. However, in the present experiment, we used an AlN template for the growth of a GaN thick film [15–18]. Therefore, an LT-buffer was not necessary and the high-temperature GaN (HT-GaN) growth was enough to obtain a high-quality GaN film. However, our experimental results revealed that when using HVPE-GaN on AlN templates, a buffer layer growth at an intermediate temperature (~900 °C) is helpful for improvement of the crystallinity of HT-GaN. This was a curious development because many reports [19] have indicated that a high growth temperature (> 1000 °C) is essential to obtain high-quality GaN film. Note that sample A was fully grown at 1040 °C (10 μm), but sample B was grown at 1040 °C (5 μm) on the IT-buffer, which was grown at 900 °C (5 μm). Therefore, we decided to investigate the role of IT-buffer in order to understand the high crystallinity of sample B.

Fig. 2 shows the AFM images of samples A (Fig. 2a) and B (Fig. 2b). As shown in Fig. 2(b), sample B had a smoother surface than sample A. The root-mean square (RMS) roughness values for the samples were notably different; sample A showed a relatively rough (4.6 nm) surface, but sample B showed a smooth surface (1.0 nm). The lattice defects are known to have a strong relationship with surface morphology and with the strain of the film [20]. Hence, the results shown in Fig. 2 imply a considerable difference in the structural quality of the two samples.

Fig. 3 shows the XRD rocking curves for GaN symmetric (0 0 2) and asymmetric (1 0 2) reflections. Sample A (Fig. 3a) showed an FWHM of 231 and 249 arcsec for (0 0 2) and (1 0 2) reflections, respectively. Sample B (Fig. 3b), however, showed an XRC FWHM of 128 and 1239 arcsec for (0 0 2) and (1 0 2) reflections, respectively. It is well-known that the FWHM of an X-ray rocking curve includes various information such as crystal size effect, local strain, and defect density in the film. When a film has a thickness of a few tenths of a micrometer, one can neglect the

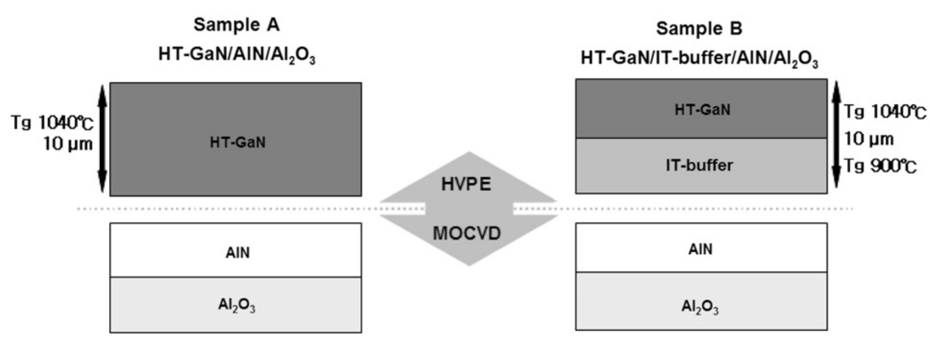

Fig.1. Sample structure of GaN films: (a) without buffer layer; sample A and (b) with IT-buffer; sample B.

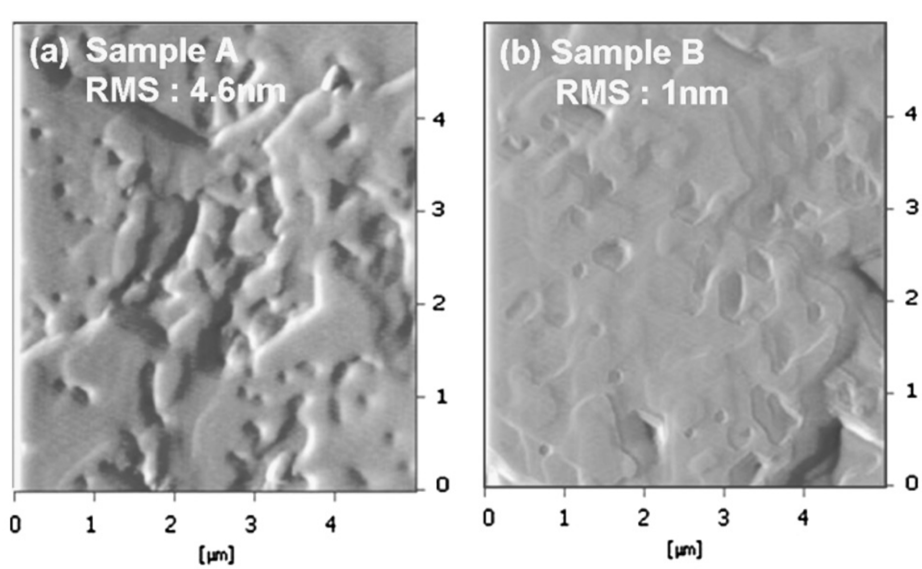

Fig. 2. AFM images of GaN samples: (a) sample A and (b) sample B.